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Synergies between biodiversity conservation and ecosystem service provision: Lessons on integrated ecosystem service valuation from a Himalayan protected area in Nepal

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ABSTRACT

Many protected areas are under pressure from growing human populations. Quantifying ecosystem service provision is increasingly seen as a critical component of arguments for future conservation of these areas. We utilised a practical approach to integrated ecosystem service valuation to inform decision-making at Shivapuri-Nagarjun National Park in Nepal. The Toolkit for Ecosystem Service Site-based Assessment (TESSA) was used to compare ecosystem services between two alternative states (remaining a protected area or no protection with consequent changed land use) of the site to estimate the net consequences of protection. Based on this hypothetical but plausible land-use change we estimated that no protection would substantially reduce the annual ecosystem service flow, including a 74% reduction in the value of greenhouse gas sequestration, 60% reduction in carbon storage, 88% reduction in water quality (not valued in monetary terms), and 94% reduction in nature-based recreation. Overall we estimated the net benefit of the park (based only on those services valued economically) to be at \$3.74 million per year. However, the benefits are mainly accrued to downstream water users and the global community (through tourism and global climate regulation). Communities adjacent to the park suffer opportunity costs of not being able to access land within the park for farming. We conclude that: (1) both biophysical indicators and monetary values can be usefully employed to determine the ecosystem service benefits of land-use change, but monetary benefits should be subject to additional sensitivity analysis; (2) simplified cost-benefit analysis between alternative states is useful for identifying potential trade-offs between services, and between beneficiaries and conservation costs; (3) continued protection of biodiversity can preserve carbon stock whose monetary value remains virtual unless an effective governance option is proposed; and (4) a buffer zone around the National Park in which communities receive a portion of park revenue may improve sharing of benefits currently provided by the park.

Highlights

- TESSA is used for integrated ecosystem services valuation of Shivapuri-Nagarjun National Park.
- Net ecosystem service value of protecting the Park was estimated at \$3.74 million y^{-1}.
- No protection could reduce carbon stock by 60% and have net economic loss of 19%.

- Conservation and ecosystem service provision were congruent at site-level.
- A buffer zone around the Park may improve benefit sharing.

1. Introduction

For centuries, protected areas (PAs) have played a fundamental role in the protection of biodiversity and ecosystems (Juffe-Bignoli 2014; Mascia et al. 2014; Palomo et al. 2014). Conservationists have argued for the designation and effective management of PAs and for the protection of critical sites for biodiversity – such as Biodiversity Hotspots, Global 200 regions, Important Bird and Biodiversity Areas (IBAs), Key Biodiversity Areas, National Parks and Wildlife Reserves – on the basis of the importance of certain sites for the species, biotic communities or habitats they contain, often emphasising their degree of threat and/or irreplaceability (Juffe-Bignoli 2014). However, these arguments, which rest on emphasising the intrinsic value of biodiversity and the associated ethical reasons for its conservation, have not become mainstreamed with the wider public or political decision-makers. This is evidenced by the continual decline of biodiversity (Butchart et al. 2010) and widespread downgrading, downsizing and degazettement of PAs (PADDD) over the last century (Mascia et al. 2014); a trend which continues to threaten biodiversity.

To address PADDD, many conservationists have sought to strengthen the case for conserving sites by demonstrating that they also provide significant benefits (i.e. ecosystem services) to people and that these benefits can be attributed a monetary value that resonates at a policy level (Balmford et al. 2002; Fisher et al. 2015). Communicating the economic value of goods and services from a site, and their contribution to well-being, helps highlight the growing costs to people of biodiversity loss and ecosystem degradation (TEEB 2010). However, assessing economic benefits of biodiversity and ecosystems alone cannot capture a comprehensive picture of nature's services. In order to account for the true value of the site, it is essential to recognise value pluralism (i.e. multiple distinct values derived from nature that are not reducible to a single [economic] metric) and measure not only the monetary value but also the site's contributions in terms of sociocultural and ecological values (i.e. an integrated ecosystem service valuation; Palomo et al. 2014).

Moreover, the influence of the social, political and cultural context under which resources and benefits are accrued to people is important, in particular the issue of equity and imbalances in power. Many interventions have (sometimes unwittingly) altered the distribution of natural resources benefits, creating winners and losers (especially among those people most directly dependent on natural resources), so undermining their development objectives and becoming the basis of local opposition and rejection (Vira et al 2012). Pre-existing conditions influence whether people are able to access decision-making processes, resources and hence benefits and specific land uses will result in asymmetries in the distribution of environmental benefits and costs between beneficiaries (McDermott et al. 2013). This context has an impact on the subsequent design and implementation of management strategies that build from the ecosystem services assessment.

According to Gómez-Baggethun et al. 2014 an integrated ecosystem service valuation of a site should have the following features. First, the multiple values from the integrated valuation should be able to identify the associated trade-offs and synergies between services and between beneficiaries (Howe et al. 2014). Second, the valuation should be based on different knowledge systems (e.g. scientific knowledge, lay knowledge, traditional indigenous knowledge, etc.). Third, both qualitative (e.g. narrative records) and quantitative information should be utilised. Fourth, values emerging at different levels of societal organisation (e.g. individual, communities, nations and global) should be considered. Last, the valuation should accommodate different valuation methods and their rationalities. Together, these features of an integrated valuation can help to elicit a deeper understanding of the ecosystem services provided by an area of conservation significance, and how different decisions affect their distribution (and costs) among stakeholders.

Despite the vast number of recent scientific publications referring to the ecosystem services concept, there is a paucity of empirical studies that conduct integrated valuation of ecosystem services provided by conservation at the site scale (e.g. Bhagabati et al. 2014). Many studies have focused on broad-scale studies at the global or regional level or intensive, long-term research (e.g., EcoAIM – Ecological Asset Information Management; Exponent 2012) or have used desk-based models (e.g., InVEST – Integrated Valuation of Ecosystem Services and Tradeoffs; Tallis et al. 2013) and methods that require advanced technical knowledge (e.g., ARIES – Assessment and Research Infrastructure for Ecosystem Services; Bagstad et al. 2011).

However, these methods require data and capacity which are often limited in areas where biodiversity is threatened.

The general objective of this study was to develop and utilise a practical approach to integrated valuation that could rapidly produce locally-robust, plural values to help to guide management and policy decisions at a site. Specifically, we used the Toolkit for Ecosystem Service Site-based Assessment (TESSA; [Peh et al. 2013a, b]; available at http://tessa.tools/) to quantify the economic and social benefits of services provided by a mountain watershed National Park in Nepal in order to investigate if the protection of an area of biodiversity importance also conserves its ecosystem service provision. We assess the changes to ecosystem services and their distribution in a plausible alternative state of the site, and interpret this information in relation to potential management strategies that continue to protect the site while helping to share the costs and benefits of conservation more fairly among stakeholders.

2. Methods

2.1. Study area

Shivapuri-Nagarjun National Park (SNNP; hereafter called the park; Fig. 1) was established in 2002 and covers an area of 15,900 ha consisting of two forest blocks located between 27°45'–27°52'N and 85°15'–85°3'E in the central region of Nepal close to Kathmandu. The original Shivapuri forest block (14,400 ha) is demarcated by stone walls and in 2009, Nagarjun forest block (1,500 ha) was gazetted. The park has been declared an Important Bird Area for its significant populations of bird species characteristic of the Sino-Himalayan Temperate Forest biome (Baral and Inskipp 2005) and is the only protected area in the country that falls entirely within the mid-hills mountain range, with its lowest altitude at 1320 m asl and highest at 2732 m asl.

Approximately 82 % of the park area is forested, comprising: (1) oak-dominated forests; (2) *Schima-Castanopsis*-dominated forests; and (3) pine forests (Table 1). The oak (*Quercus semecarpifolia*)-dominated patches are the mature forests that occur on the steep slopes above 2000 m asl. At lower elevations, *Schima-Castanopsis*-dominated fragments are the successional forests, recovering from heavy logging that occurred prior to the 1970s. Pine forests consist mainly of chir pine *Pinus roxburghii* introduced for afforestation purposes. Much of the remaining area is shrubland with small areas of grassland. Approximately 3% remains as agricultural land due to the continued presence of two human settlements with a total of 350 households. These settlements are permitted to remain inside the park but they are not allowed to harvest wild species within the area.

The park is a major water source for the Bishnumati, Mahadev Khola and Bagmati rivers of the Kathmandu Valley. There are 28 villages with a total of 80,000 inhabitants living in close proximity to the park's boundaries. The immediate area around the park is a mosaic of terraced rice paddy, hillslope agricultural plots, and built-up residential areas with home gardens, which has expanded up the hillslopes in recent years. However, in contrast to many parks in Nepal, recent encroachment into the park by other land-uses such as agriculture is currently non-existent due to (1) the clear demarcation of the park – with a wall – and the fact that it is not possible to receive a land tenure certificate for any land within the boundaries of the park; and (2) frequent patrolling of the park's boundaries by the national army employed as park rangers. In the past ten years a rigid protection regime has been imposed by the park authorities to prohibit extractive activities. Being surrounded by a human-dominated landscape, the park provides a context in which to study the impact of site protection on ecosystem service provision at a range of spatial scales.

2.2. Measuring ecosystem services

The study, carried out in November – December 2010 pioneered the use of TESSA (Peh et al. 2013a) to assess the net value of the park. TESSA aims to guide local management and policy decisions and was chosen over other tools because it has been designed to be used: in situations where there are few existing data; by personnel who have limited technical knowledge, capacity and time (conditions at the Nepal Department of National Parks and Wildlife Conservation [DNPWC]); and at relatively low cost (Peh et al. 2013b).

Using TESSA, we compared empirical measurements from the park with those from a nearby comparison site, carefully chosen to represent the most plausible alternative state of the park. The process comprised: (1) engaging stakeholders to determine what the alternative state was likely to be; (2) estimating the likely area of each land cover type in the park under the alternative state; and lastly, (3) taking direct relevant measurements, wherever possible, at the comparison site to assess the likely change in ecosystem service provision under alternative land use. The delivery of ecosystem services from the park in its current state could then be compared against this plausible alternative. The comparison of the two states (protection versus no protection leading to land use changes) was required in order to assess net costs and benefits (rather than just total values) of conservation, and to reveal who gains and who loses from continued conservation of the site.

The most plausible alternative state of the park was determined through a focus group discussion with the chief conservation officer of the park, three park wardens, four local environmental organisation (Bird Conservation Nepal, BCN) members, three representatives of an international environmental organisation (BirdLife International) and one university researcher. Among these stakeholders, the chief conservation officer, the park wardens and all BCN members had local knowledge of the park from their work experience or long-term field observations. The participants used a topographical map to estimate how the land use would have changed in the event that the park had not been protected. The park's position overlooking Kathmandu means that its land and resources are under great pressure, especially from encroaching agriculture and urbanisation. Hence all stakeholders agreed that the most plausible alternative state was the conversion of forest into agricultural and residential areas (i.e., no protection status, Table 1), typical of the surrounding areas. Although the estimated land cover of each habitat type under the alternative state is not spatially explicit, the output (expressed in ha; table 1) has taken the area's climatic conditions, altitude, slope, and soil type into account. Sites that best reflected the expected agricultural and settlement expansion were the human-dominated landscape surrounding the park, which were then used for measuring the services that would have been delivered under this alternative state.

A preliminary scoping assessment of the range of ecosystem services delivered by the park was also conducted at the same focus group discussion. The purpose of this exercise was to identified the key ecosystem services (according to the CICES classification) and their associated beneficiaries. From this list, we selected four key services for further study, based on their (1) relative importance, (2) likelihood of being affected by the land use change, and (3) measurability by using TESSA: global climate regulation, water services (water production and prevention of water sedimentation from soil erosion), nature-based recreation and tourism, and provision of cultivated goods. Methods for measuring the selected ecosystem services were based on Peh et al. (2013a) and are summarised below (for details see Supporting Information S1). The identification of the beneficiaries was based on the diverse knowledge systems (e.g. local ecological knowledge, formal scientific knowledge, etc.) of the participants, further substantiated by field observations when measuring the associated ecosystem services. We converted all monetary values in this study from Nepalese rupees to US dollars using the exchange rate at November 2010 (NR72.50:US$1.00). It is beyond the scope of TESSA to perform full life cycle analysis of costs and benefits, and we did not consider time horizons and discount rates. Instead, our study was designed to provide an indicative comparison of two different states of the reserve as 'snapshots' in time. Therefore, the assessment does not consider changes in the delivery of services over the long-term.

Global climate regulation – We assessed carbon storage and fluxes of greenhouse gases (CO_2, CH_4 and N_2O) for the park under the current (protection) and alternative (no protection) management regime, based on a combination of field data and appropriate, published, peer-reviewed values (for details see Supporting Information S1). We estimated the potential range in economic values of carbon stock and overall greenhouse gas fluxes using six estimates of the price of carbon (see Table S1).

Water-related services –As recommended in TESSA, we used the WaterWorld Policy Support System v. 2.4 (hereafter WaterWorld; http://www.policysupport.org/waterworld; Mulligan & Burke, 2005; Mulligan et al. 2010) to assess the current hydrological baseline for monthly water balance, runoff and soil erosion (as a proxy for water quality). To assess the impacts of land use change, we applied the plausible alternative state as a land use 'policy option' (for details see Supporting Information S1).

Cultivated goods – We estimated the average annual value of agricultural production per hectare by surveying households from two wards within Tokha and Budhanilkantha municipalities near the park (for details see Supporting Information S1 and S2). The mean per hectare was then multiplied by the total number of hectares of cropland in the current state (a small area linked to the two settlements inside the park) and under the alternative state to estimate how the total value of cultivated goods would change if the park was not under protection.

Nature-based recreation and recreation – We estimated the value of nature-based tourism from the direct expenditure by local and international visitors to the park. We carried out a field survey at the two main access points to the park using a questionnaire to obtain information on expenditure on travel, food, and guides, and likelihood of people visiting the park under the alternative state (for details see Supporting Information S1 and S3).

Conservation and farming costs –The costs of conservation were estimated from the annual park management budget (provided for 2011 by the park warden), which includes the costs for employing national army personnel in the park (Supporting Information S1) and the opportunity cost of farming was represented by the agricultural production survey (for details see Supporting Information S1 and S2). The mean cost per hectare was then multiplied by the total number of hectares of cropland in the current state and under the alternative state.

One-off windfall benefit – We estimated the monetary one-off benefit of harvesting timber and fuelwood during conversion to the alternative state, based on information gathered from our field surveys on above-ground biomass of oak and pine trees, and interviewing local timber yards for the prices of wood products (Table S2; for details see Supporting Information S1).

3. Results

The most plausible alternative state was the conversion of substantial portions of oak-dominated forest, *Schima-castanopsis* forest and pine forest into agricultural and residential areas (i.e., no protection status; Table 1), typical of the surrounding areas. We summarize the net quantity or value of each ecosystem service resulting from such a change in land-use below.

Global climate regulation –We estimated that the above-ground carbon stored in live trees in the oak-dominated forest, mixed *Schima-Castanopsis*-dominated forest and pine forest averages 284

Mg ha^{-1}, 57 Mg ha^{-1} and 52 Mg ha^{-1} respectively; these estimates fall within published ranges for these forest types (Table S3). The total above-ground carbon storage within the park is estimated to be 2.40 million Mg C, with the old-growth in the oak-dominated forest accounting for 84 % of this carbon storage. We estimate the total carbon (above-ground biomass, below-ground biomass, litter, dead wood and soil) to be 4.50 million Mg C (Table 2; for details see Table S4). The total above-ground live biomass of all habitat types and the total above-ground live biomass in the oak-dominated forest accounted for 49 % and 41 % of the total carbon storage, respectively (Table S4). Loss of protection of the park would, our stakeholders suggest, result in an eight-fold increase of croplands and about 3400 ha of residential development. In addition, the area of shrubland would increase by approximately 42% (Table 1). We estimated that the total above-ground live carbon storage would decrease by 71% under no protection and the total carbon storage (from the pools of above-ground biomass, below-ground biomass, litter, dead wood and soil) would decline by 60% (Table S4; Fig. 2). Based on a monetary value of $83.61 $Mg^{-1}C$ (2007 price from US Government value [Greenspan Bell and Callan, 2011] adjusted for inflation to 2011), this would lead to a loss of $223 million-worth of stored carbon (Table S1; Fig. 2).

Both states result in net sequestration of greenhouse gases, though this would be much reduced if the park was not protected. We estimate the a total of 96,539 Mg CO_2eq is sequestered annually by the area in the protected state (Table 2), compared to 25,323 Mg CO_2eq in the alternative state (a 74% reduction; Fig. 2). This translates into a benefit of protection from avoided carbon loss of $1.62 million annually, based on an economic value of $22.78 $Mg^{-1}CO_2$eq (Table S1).

Water provisioning – The main water intakes for Kathmandu are located near the park boundary (Sundarijal, 27.75 N, 85.41 E) and farther downstream within the urban area (Mahadev Khola: 27.79 N, 85.37 E and Nagarjun 27.73 N, 85.3 E). We assessed how water flows would change in the absence of protection using the WaterWorld Policy Support System to change the coverage of trees, herbs and bare ground from 56%, 44% and 0% (estimated in WaterWorld for the year 2000) to 20%, 59% and 21% (based on land cover change in Table 1) respectively. This is associated with increased tree cover in parts of the sparsely forested northern slopes but decreases elsewhere. The reduced tree cover leads to reduced evapo-transpiration of around 18%

and reduced cloud water interception (*sensu:* Bruijnzeel et al, 2011) of 15%, leading to an overall increase in water yield of 24% for the park. This would result in greater runoff for the rivers draining into Kathmandu of 0.72 %, 0.69%, and 1.34 % for the Bishnumati, Mahadev Khola and Bagmati, respectively. However since the park covers only part of the catchments draining into Kathmandu, by the time these rivers reach the city the impact of the land use change is reduced (Fig. 3) to increases in annual flow of 0.1–0.3%. As the park currently discharges 226.7 million L per day, providing a surplus supply of water to Kathmandu (Kunwar 2008), an increment of annual flow (i.e. an additional 2.2 – 6.8 million L per day) as the result of land use change would have little impact on water provisioning for the downstream users.

Water quality – Based on WaterWorld, net soil erosion within the park is projected to increase by an average of 8.5 mm/y as a result of this land use change, with consequences for the sustainability of the new agricultural land and for water quality downstream. This translated to 88% reduction in water quality (Fig. 2). The model output suggests that sediment transport by the rivers entering Kathmandu is observed to increase under conversion but the magnitude of increase varies spatially. Though the alternative state will produce a little more water on an annual basis, this water will arrive with substantial deterioration in quality.

Cultivated goods – Potatoes, rice, wheat, maize, buckwheat, and livestock fodder were the main crops. The average annual value of these mixed-croplands was US$1,872 ha^{-1}. Applying this value to the area under cultivation in both protected and non-protected states (Table 1), the total annual agricultural values were estimated at $1.44 million and $12.2 million respectively. These values should then be offset by farming costs at $1.18 million in protected state and $9.96 million in protected state (Table 3).

Nature-based recreation and tourism– Annual paying visits numbered 167,830 (11,957 international and 155,873 nationals), although this under-estimates total visits because the park grants free access to a large number of school groups and other visitors such as diplomats and researchers. We interviewed 33 international visitors and 60 national visitors. National visitors reported frequently coming to the park to spend time with family and friends and to visit temples and religious sites. On average, international visitors spent $299 per person on their visit and national visitors spent \$4.60 per person. The estimated total expenditure generated from all visits was \$4.38 million y^{-1}. When asked if they would visit the area in the alternative state, 33% of national visitors and 0% of international visitors said that they would. Therefore, the estimated total value of nature-based recreation attributed to the park under the alternative state was \$262,682 y^{-1} (Table 3; Fig. 2).

Conservation costs and one off windfall benefit – The annual park management budget for 2010/11 was \$200,000. The budget for employing army personnel in 2010/2011 was \$2.89 million y^{-1}. Therefore the total annual conservation cost was estimated at \$3.09 million. During conversion of the park to the alternative state land-use, a one off benefit from the wood products would be gained in the form of timber (oak and pine) and fuelwood (mainly deadwood). Using standardised conversion factors from IPCC (2006) and local market values for these products, the net benefit (minus harvesting and processing costs) is estimated at \$18.6 million from timber and \$14,238 from fuelwood (Table S3). Hence, the decision to conserve the park's forest imposes on the Nepalese government an opportunity cost of \$18.6 million over the course of one cutting cycle. Conversely, based on a simple cost-and-benefit analysis (Table 3), the protection of the park yields a net stock benefit of \$225 million and a net annual benefit of \$709,000. However, these economic gains are mainly societal benefits through global climate regulation services.

Overall summary of results – The net annual benefit of the service flow and the net stock benefit provided by the protected area are estimated to be \$3.74 million (or \$236 ha^{-1}) and \$407 million (or \$25,578 ha^{-1}), respectively, using the US Government price for CO_2 of \$22.78 Mg^{-1} CO_2 (Table 3). The overall difference in net annual value of services from the area in the presence and absence of protection is estimated at \$534,063 (\$34 ha^{-1} y^{-1}; Table 3). The estimated difference in net value of carbon stock between these states is \$226 million (Table 3).

Although overall we are confident that the results presented are a meaningful comparison between the two alternative states, there are varying levels of uncertainty related to the accuracy and precision of the data for each ecosystem service. We used a simple scale of 'high', 'medium' and 'low' to assess the degree of confidence in the results (Table 4). We performed an analysis of our carbon value, using a range of carbon prices (Table S1), to assess how sensitive the overall result was to a chosen carbon price. We showed that the scale of the net benefit of conservation in this study is highly sensitive to carbon prices although our results showed that there is still a net carbon stock benefit from protection of almost $66.5 million when the lowest carbon price is chosen. Therefore a critical component of valuing carbon stock is the choice of carbon prices, which depends on the purpose of the analysis. For example a carbon price based on the market value should be used for a financial project appraisal, whereas in the context of UK policy decisions (e.g. relating to overseas development aid), the carbon price provided by the UK Department of Energy and Climate Change would be appropriate.

Our analyses showed that there are significant ecosystem service benefits (from carbon, water, and nature-based tourism) from the protection of the park. However, the beneficiaries of these services are mainly district (Kathmandu water users), national (National Parks department), and global (climate regulation, biodiversity) in scale, and not the local communities living around the park (Table 4). Conversely, under the 'no protection' alternative state, the global community would lose as a result of reduced climate regulation, whereas local communities would gain by being able to expand their farming activities and to collect fuelwood during the land use conversion. The negative impacts of land-use change on water quality under the alternative state could also affect the health of downstream users (including 1.7 million urban inhabitants in Kathmandu) and the profits of the private water company (which might have to invest in improved filtration facilities). In addition, local and nearby communities would lose access to the income associated with recreational visits, although due to the presence of temples, the alternative state could still provide considerable recreational and cultural services.

4. Discussion

We provide evidence that the continued protection of a Himalayan protected area of biodiversity importance would have a net economic and social advantage for people. Our rapid assessment utilised a framework and associated tools which illustrate a practical approach to integrated valuation to inform decision-making. First, the multiple types of values (expressed in different metrics) arose from different assessment methods – including surveys to recreational visitors, quantitative ecological measurements of carbon stored in trees and the use of ecological models to quantify water flow. This enabled us to examine trade-offs and synergies between different ecosystem services; only an integrated approach could elicit such a clear trade-off between provision of cultivated goods and water quality in this context. Second, the application of the practical toolkit relies heavily on different knowledge systems; the scientific knowledge held by the researchers, lay knowledge from the conservation practitioners and local knowledge from the park wardens are all critical sources of information for enhancing our understanding of the services provided by the dynamic systems. Last, the use of the toolkit enables collection of information at different levels of societal organisation – from individuals (e.g. recreational visitors) to local communities (e.g. farmers) –for understanding the distribution of beneficiaries within and beyond the protected areas.

While this study shows the usefulness of TESSA as an integrated ecosystem service valuation tool, it also highlights the limitation of this approach. The exclusion of cultural ecosystem services in this study – spiritual and religious values, aesthetic values, sense of place, cultural heritage – that rely on qualitative information underscores the need for further developing TESSA methods to better adapt them for a truly integrated valuation. We could also improve the approach by involving a wider range of stakeholders (including local people) in the process to identify and value the benefits and costs. Furthermore, given the rapid approach, we were not able to assess all services listed at the scoping exercise, such as air quality regulation and nutrient cycling. Potential provision of harvested wild goods (e.g. fuelwood, fodder, wild fruits and vegetable, timber and fish) were also recognised if the harvesting of these goods were not prohibited by law. We speculate that all these services would have declined under the alternative state. Therefore, our estimate of net ecosystem service value lost due to the land use conversion is conservative.

In this study, we present two different types of the monetary values: those for goods that are actually considered by the market prices (e.g. harvested wood products; Table 3) and those that remain virtual unless an adequate governance option is proposed (e.g. PES or REDD+ scheme for carbon storage; Fig. 2C). The latter arguably captures a more comprehensive picture of the economic value of the protected area. Monetary benefits of services that are delivered and consumed in the absence of market transactions, however, can materialise only if there are cost-effective incentives to stimulate the conservation of such services (Adams 2014).

We have considered the distribution of economic benefits and costs of the park and how the change in land-use impacts people at different spatial scales. Our analyses show that the conservation benefits of this mountain protected area in Nepal are mainly accrued to downstream water users and the global community, through tourism and global climate regulation. Resolving such distributional issues will require a process of consultation and compromise and this would be a necessary step in any follow up to this assessment at SNNP. That decision-making process is a significant challenge as stakeholders promote their values and interests and exercise their varying degrees of power to influence the outcome. Powerful actors with entrenched interests often oppose changes to the status quo making it hard to bring about changes that have potential to deliver more socially desirable outcomes (Vira et al 2012). This can be seen within the context of Nepal's community forestry programme where equity challenges can be seen between the state and communities (recognition of rights, management autonomy, revenue sharing and service provision); between communities (impacts of herders in high mountains on users of water in the Terai); and within communities (elite capture in representation, decision-making and benefit sharing) (Paudel 2015).

The equity issues elicited in this study should be further explored to inform a sustainable management strategy for the long-term conservation of the park's biodiversity and ecosystem services. Improved benefit-sharing mechanisms could address the imbalance of benefits currently provided by the site. One option would be to establish a buffer zone around the park, as is currently being proposed in the revised management plan for SNNP (DNPWC, 2014). In Nepal, communities living within park Buffer Zones receive 30–50% of park revenue (from entry fees and any fines/penalties) for conservation and development projects. Decisions on how to use the funds are made by community-based Buffer Zone Management Committees. If a buffer zone were created in the future, the park's revenue (currently from entry fees, but potentially in the future from REDD+ payments) would enable local communities to benefit directly from conservation, though these payments are only significant if the park receives substantial income. By redressing the imbalance in the costs and benefits of conservation, and restoring some rights to local people, those who then share in the benefits from the park (the majority) are expected to apply pressure for more pro-social behaviour by those acting in ways which damage the park and put the community benefits at risk.

Another option could be the development of a fiscal instrument such as a Payments for Ecosystem Services (PES) or similar incentive scheme for watershed services. PES is still in its infancy in Nepal, but there are some private schemes in place (e.g. the Khulekhani watershed [Khatri 2009]) and a government PES policy is being formulated (coordinated by The Ministry of Forests and Soil Conservation and the Ministry of Local Development, also involving other concerned ministries and the National Planning Commission). A critical part of this is the development of a legal framework to establish who can legally benefit from water services and by how much, ensuring that upstream local communities receive fair payment for the ecosystem service benefits that their land-use management helps to deliver (Greiber 2009). Given that SNNP is an important part of the catchment for regulated, clean water supplies to the city, it would be worth exploring the feasibility of establishing a payment system between the beneficiaries of watershed protection (Kathmandu residents and the water company) and the local people who incur opportunity costs through forest protection. However, issues of equity and power imbalances again need to be considered. Although PES schemes aim to find synergies which maximise benefits to environmental stakeholders –they are not immune to the problem of trade-offs (Redford and Adams 2009). Indeed, PES schemes, by commodifying environmental services, create new relationships with land and natural resources, and new issues of ownership, responsibility and property rights (Reid and Nsoh 2014). This has also raised concerns over equity, particularly at the local level, as with the transformation in values that accompanies the entry of ecosystem services into a market system, politics and power may disenfranchise local communities, worsening local inequalities (REDD-Net 2011; Franks and Quesada-Aguilar 2014). Any exploration of the suitability of a PES scheme at SNNP needs to be mindful of the equity implications.

5. Conclusion

Although sites are generally prioritised for conservation based on their biodiversity values alone, they can provide many other services which benefit human well-being in a variety of ways and at different spatial scales. Our study shows how integrated valuation of ecosystem services in a conservation context can shed light on a site's additional value to society and indicate suitable strategies for enhancing economic sustainability and human well-being, while maintaining biodiversity values. We hope that our results will contribute to helping policy-makers recognise the values of protected areas, understand better the trade-offs involved, and address how benefits can be more equitably shared by the people who are engaged in the conservation and management of these areas. Our results support the Government of Nepal's current strategy of transferring more benefits to the local level, with promising interventions including the development of mechanisms for benefit sharing (through buffer zone creation) and PES schemes to compensate local communities for the local-level cost of restricting access to forest resources.

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Table 1. Land cover change. Estimated land cover under the current state (with protection) and alternative state (no protection) of Shivapuri-Nagarjun National Park.

Habitat type	Protection (ha)	No protection (ha)
Oak-dominated broadleaf forest	7111	1956
Schima-castanopsis forest	5248	1011
Pine forest	754	218
Shrubland	1934	2745
Cropland	771	6493
Grassland	78	78
Bareground	4	4
Built up	0	3394
Total	**15900**	**15900**

Table 2. Carbon stored and greenhouse gas (GHG) fluxes by habitat types at the Shivapuri-Nagarjun National Park under current (with protection) and alternative (no protection) states.

State	Habitat type	Carbon storage (Mg)		GHG sequestration (Mg CO2 eq y^{-1})
		Total	Potential range	Total
Protection	Oak-dominated broadleaf forest	3771384		46693
	Schima-castanopsis forest	703712		34461
	Pine forest	93686		4952
	Shrubland	262991		11805
	Cropland	29575		-1479
	Grassland	2643		107
	Bareground	131		0
	Built up	0		0
	Total	4864122	3512878 - 6215367	96539
No protection	Oak-dominated broadleaf forest	1037512		12845
	Schima-castanopsis forest	135530		6637
	Pine forest	27134		1434
	Shrubland	373346		16758
	Cropland	249152		-12459
	Grassland	2643		107
	Bareground	131		0
	Built up	115405		0
	Total	1940853	1174262 - 2707443	25323

Table 3. Net values of ecosystem services (those for which monetary values were available) resulting from protection of Shivapuri-Nagarjun National Park. Values of greenhouse gas regulation are based on a mid-value US Government price for carbon (see Table S1)

	Protection ($) (15,900 ha)	No protection ($) (15,900 ha)	Difference ($) (15,900 ha)	Difference ($ ha-1 y^{-1})
Service flow ($ y-1)				
Greenhouse gases sequestration	2,199,162	576,852	1,622,310	102
Cultivated goods	1,442,926	12,155,720	10,712,794	674
Nature-based tourism	4,378,815	262,682	4,116,133	259
Conservation costs	3,093,981	0	3,093,981	195
Farming costs	1,182,231	9,959,540	8,777,309	552
Net annual benefit	3,744,691	3,035,714	708,977	45
Net annual benefit per hectare	236	191	45	
Service stock ($)				
Carbon storage	406,689,254	162,274,679	244,414,575	15,372
One-off benefit from harvest wood products during conversion	0	18,629,761	18,629,761	1,172
Net stock benefit	406,689,254	180,904,440	225,784,814	14,200
Net stock benefit per hectare	25,578	11,378	14,200	

Table 4. Magnitude of change in delivery of different ecosystem services if the site were converted from the current (protection) to the alternative (no protection) state, shown for beneficiaries at the local, national and global scale. "↑" indicates increase, "↓" indicates decrease, "=" indicates no change, and number of symbols indicates relative magnitude of change. Level of confidence estimates provided for each service valuation are based on the classification scheme provided in TESSA (Peh et al. 2012).

	Location of beneficiaries				Level of confidence over estimates	Comments on level of confidence
Ecosystem service	Local	District	National	Global		
Change in annual flows if converted						
Greenhouse gas sequestration	=	=	=	↓↓	Low	Estimates were based on look-up values – from scientific literature – derived from small sample sizes.
Water provision	↑	↑	=	=	Low	Estimates were derived by treating vegetation biophysically rather than as particular crop/management complexes and were based on global datasets, limiting their accuracy at local scale. This could be improved through incorporating better local data where available.
Water quality	=	↓↓↓	=	=	Low	As above; estimates could be improved by incorporating local level maps
Cultivated goods	↑↑↑	=	=	=	Medium	Estimates were derived using field measurements but from relatively small sample sizes.
Nature-based recreation	=	↓↓↓	↓↓↓	↓↓↓	Medium	Estimates were based on existing published data combined with field surveys but from relatively small sample sizes.
Change in stock if converted						

Carbon storage	=	=	=	↓↓	Medium	Estimates were derived from field measurements but using relatively small sample sizes and generic allometric equations at the level of genus or forest type. Site boundary definition, area stratification, and classification of forest types were robust.
Wood products	↑↑↑	=	=	=	Medium	Estimates were based on field surveys, and visits to local timber yards, combined with conversion factors from IPCC (2006).

Figure legends

Figure 1. Location of Shivapuri-Nagarjun National Park in Nepal. The National Park consists of two sections: Shivapuri and Nagarjun.

Figure 2. Rose plots to show changes in ecosystem services between the current (A, protection) and the alternative state (B, no protection) for annual flows of greenhouse gas sequestration, water provision, water quality, cultivated goods and nature-based tourism (for which 1 equates to the maximum value in either state for each service); and bar chart of one-off stock changes (C) that would occur during conversion to the alternative state.

Figure 3. Screen capture from WaterWorld showing areas of increased annual runoff (green to red) for the alternative state (no protection) of the site expressed as a percentage of current runoff (based on a baseline in the year 2000). Map: Google, AutoNavi (2012).
http://support.google.com/maps/bin/static.py?hl=en&ts=1342531&page=ts.cs

Fig.1

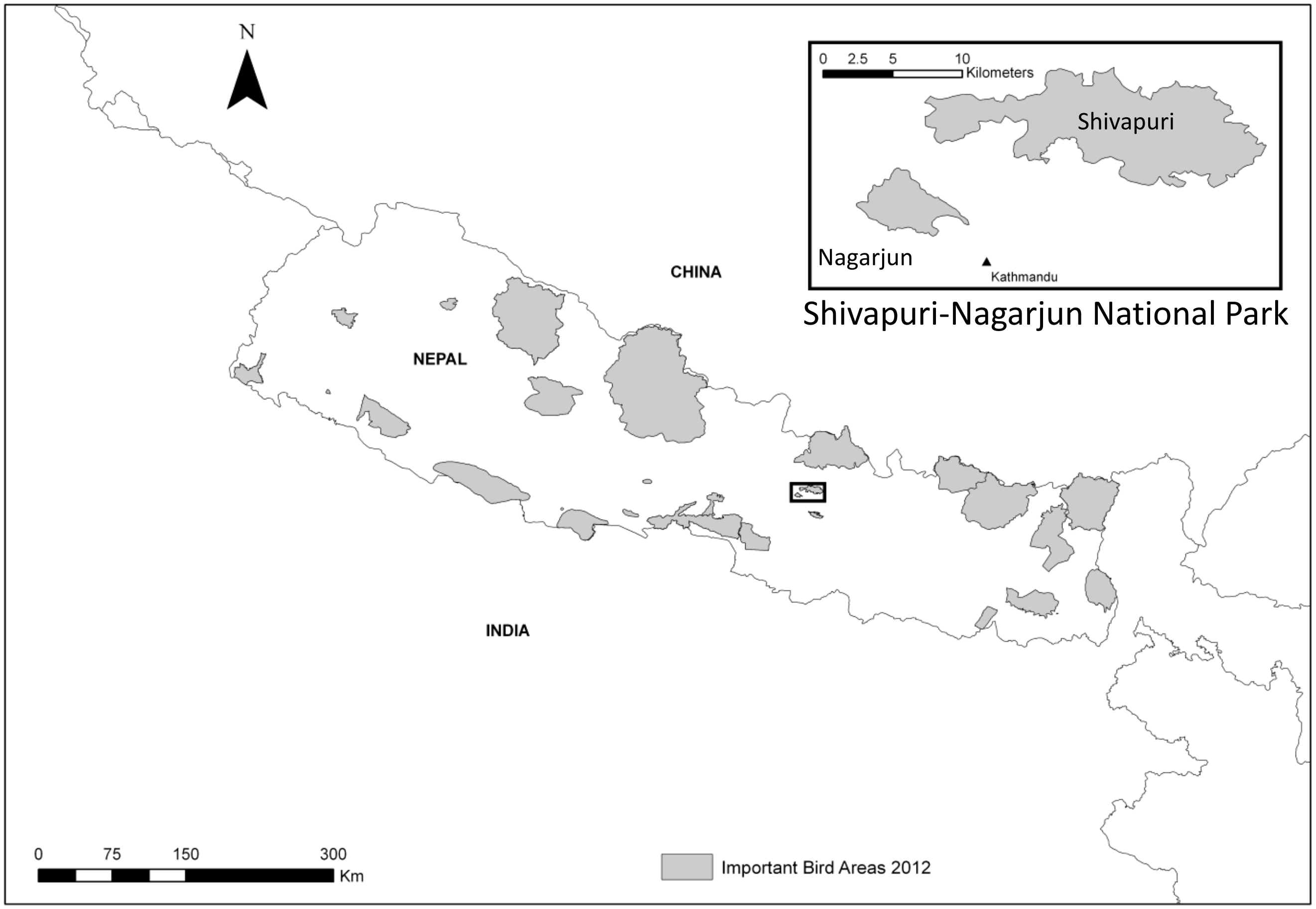

N
CHINA
NEPAL
INDIA
0 2.5 5 10
Kilometers
Shivapuri
Nagarjun
Kathmandu
Shivapuri-Nagarjun National Park
0 75 150 300
Km
Important Bird Areas 2012

Fig. 2

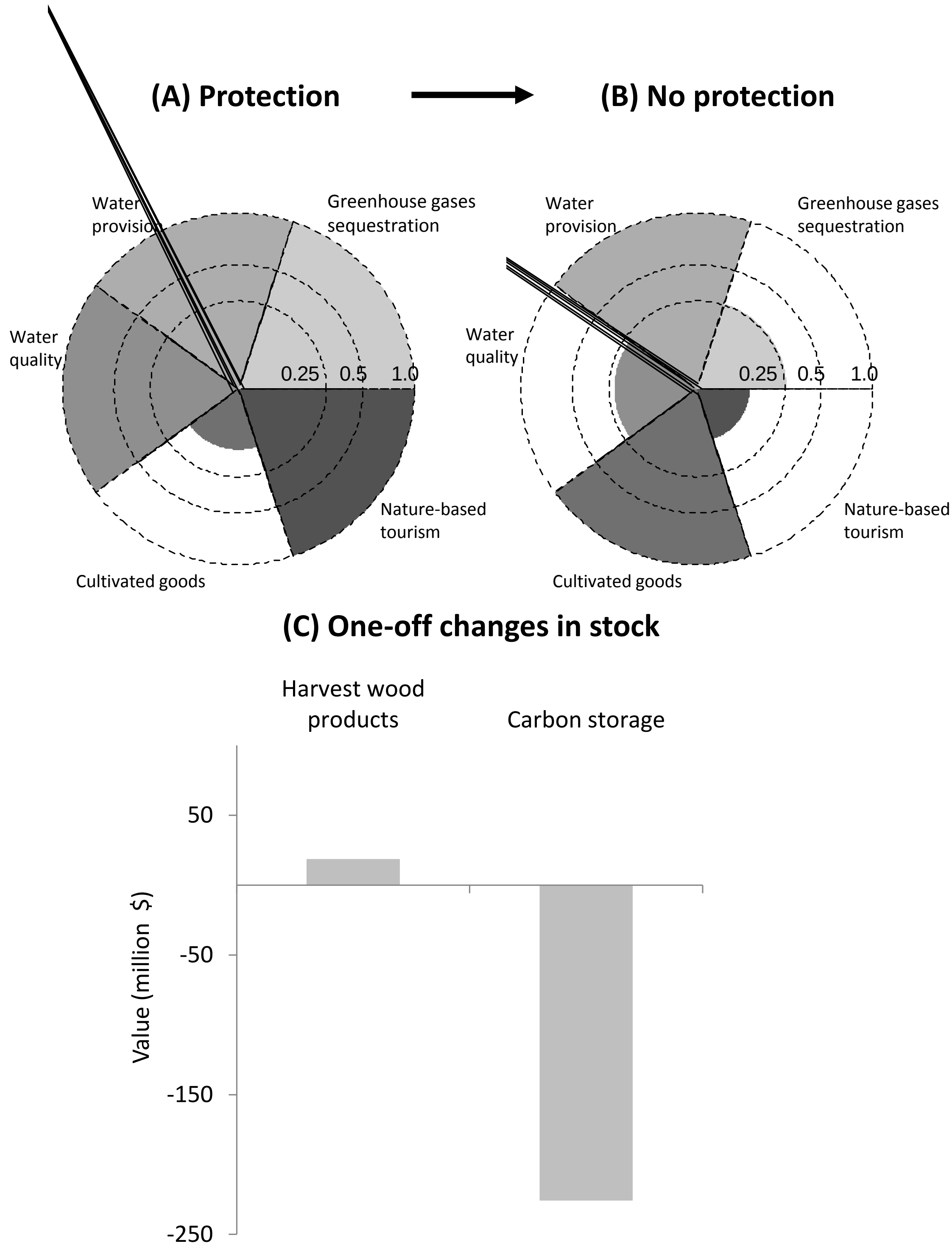
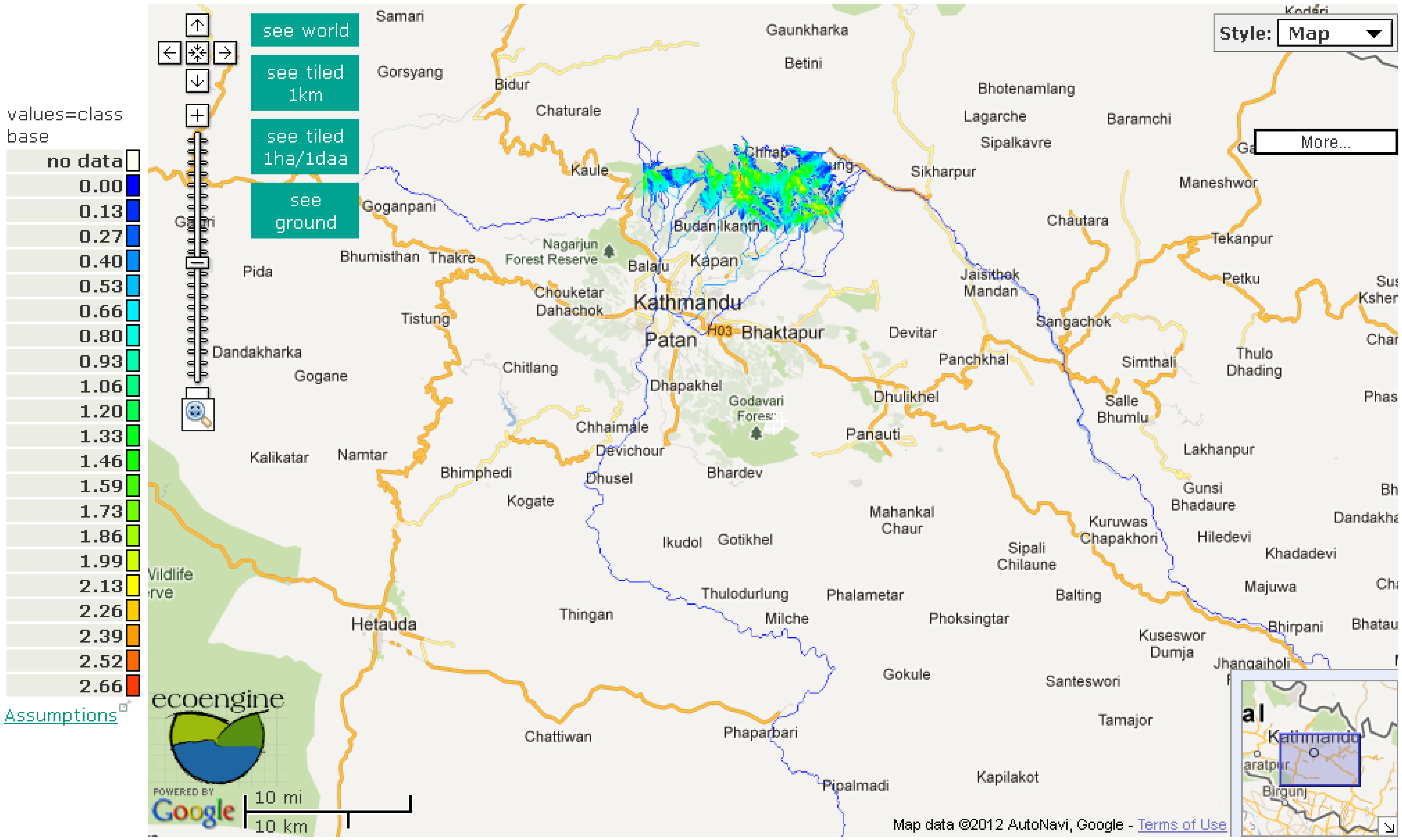

(A) Protection
(B) No protection
Water provision
Greenhouse gases sequestration
Water quality
0.25
0.5
1.0
Nature-based tourism
Cultivated goods
Water provision
Greenhouse gases sequestration
Water quality
0.25
0.5
1.0
Nature-based tourism
Cultivated goods
(C) One-off changes in stock
Harvest wood products
Carbon storage
Value (million $)
50
-50
-150
-250

Fig. 3


values=class base
no data
0.00
0.13
0.27
0.40
0.53
0.66
0.80
0.93
1.06
1.20
1.33
1.46
1.59
1.73
1.86
1.99
2.13
2.26
2.39
2.52
2.66
Assumptions
see world
see tiled 1km
see tiled 1ha/1daa
see ground
Style: Map
More...
Samari
Gaunkharka
Betini
Gorsyang
Bidur
Chaturale
Bhotenamlang
Lagarche
Sipalkavre
Baramchi
Maneshwor
Kaule
Sikharpur
Goganpani
Budanilkantha
Chautara
Tekanpur
Nagarjun Forest Reserve
Balaju
Kapan
Bhumisthan
Thakre
Pida
Jaisithok Mandan
Petku
Chouketar Dahachok
Kathmandu
Sangachok
Tistung
Patan
H03
Bhaktapur
Devitar
Dandakharka
Panchkhal
Simthali
Thulo Dhading
Gogane
Chitlang
Dhapakhel
Godavari Forest
Dhulikhel
Salle Bhumlu
Chhaimale
Panauti
Kalikatar
Namtar
Devichour
Lakhanpur
Bhimphedi
Dhusel
Bhardev
Gunsi Bhadaure
Kogate
Mahankal Chaur
Kuruwas Chapakhori
Hiledevi
Ikudol
Gotikhel
Sipali Chilaune
Khadadevi
Majuwa
Thulodurlung
Phalametar
Balting
Thingan
Milche
Phoksingtar
Hetauda
Kuseswor Dumja
Bhirpani
Bhatau
Jhangajholi
Gokule
Santeswori
Tamajor
ecoengine
Chattiwan
Phaparbari
Pipalmadi
Kapilakot
POWERED BY Google
10 mi
10 km
Map data ©2012 AutoNavi, Google - Terms of Use
Kathmandu
Birgunj

Appendix A. Supplementary material

Supporting Information S1.

Methods

Global climate regulation –To estimate the carbon storage in above-ground biomass (AGB), we stratified the park according to land cover classes: oak-dominated forest; *Schima-Castanopsis*-dominated forest; pine forest; shrubland; grassland; and cropland. In total, we surveyed nine transects in the oak-dominated forest, six transects in the mixed *Schima-Castanopsis*-dominated forest, and six transects in the pine forest totalling 0.92 ha. We measured diameters at breast height (dbh) following standard protocols (Phillips *et al.* 2009) for all trees ≥ 10 cm along 5 m x 100 m stratified-random transects in the Shivapuri block. The AGB of each tree was estimated using regression models developed for temperate forest involving dbh (D):

$$AGB_{oak} = \exp(-2.0127 + 2.4342 \times \ln D) \tag{1}$$

$$AGB_{pine} = 0.887 + ((10486 \times D^{2.84})/(D^{2.84} + 376907)) \tag{2}$$

$$AGB_{general} = 0.5 + ((25000 \times D^{2.5})/(D^{2.5} + 246872)) \tag{3}$$

Equation 1 was used for *Quercus* species (Jenkins *et al*. 2003) and equation 2 for *Pinus* species (Brown and Schroeder 1999). We used equation (3) for all other tree species (Schroeder *et al*. 1997). These equations are widely accepted and commonly used in the literature (e.g. Pearson et al. 2005). The amount of carbon stored in a tree was assumed to be 50% of the above-ground biomass (Chave *et al*. 2005). To determine sample size, we estimated carbon stocks (Mg C ha^{-1}), standard deviations and variances from six preliminary transects in each forest type to work out the required number of transects needed to achieve a precision level of 20% (for the formula, see Pearson *et al*. 2005). No loss of biomass carbon stocks due to disturbance, such as wood harvesting, charcoal removal and fire, was reported from the park.

The estimates of carbon stocks in AGB for oak-dominated broadleaf forest, *Schima-castanopsis* forest and pine forest were measured using data collected on site. The AGB of shrubland, cropland, grassland, and soil were drawn from the IPCC (2006) tier 1 database. The estimates of stored carbon in BGB for all habitats were calculated using a below-ground biomass to above-ground biomass ratio (conversion factors) for a particular habitat type (IPCC 2006). The estimates of carbon stocks in litter were calculate using conversion factors from IPCC (2006). The maximum and minimum deadwood carbon stocks in forests and shrubland were estimated by multiplying those of AGB with a conversion factor of 0.1 and 0.4, respectively (Brown 1997, Marklund and Schoene 2006). The estimates of carbon stocks of bare ground and residential areas were assumed to be insignificant. The estimates of stored carbon in soil were drawn from IPCC (2006). The IPCC guidelines suggest a nominal error of ±90% for soil. Above-ground carbon (and hence BGB) is calculated to a precision of 20%. We used these per hectare values to calculate the carbon storage under the current and alternative state.

Greenhouse gas sequestration rates (carbon dioxide, methane and nitrous oxide flux) for both states were estimated using published data (Anderson-Teixeira and DeLucia 2011). All figures were converted to carbon dioxide equivalents (expressed as tons of carbon dioxide equivalents [Mg CO_2Eq]) by multiplying tons of gas by the associated global warming potential (GWP): Mg CO_2Eq = tons of a greenhouse gas x GWP, where the GWPs of carbon dioxide, methane and nitrous oxide are 1, 23 and 296, respectively (IPCC, 2006).

Hydrological services – Rainwater captured by the park serves the population of 2.5 million people living in the Kathmandu Valley (Government of Nepal, 2011). Field analyses of hydrological ecosystem services and the impact of land use change upon them require sophisticated instrumentation. Such studies require long term measurements in order to account for climate variability and temporal changes in soil and vegetation after land use change. Since this was a rapid assessment, we used the WaterWorld Policy Support System v. 2.4 (hereafter WaterWorld; http://www.policysupport.org/waterworld; Mulligan & Burke, 2005; Mulligan et al. 2010), a web-based spatial modelling system, to understand the hydrological baseline and the impacts of land use change by combining knowledge of hydrological processes with locally specific data for the controlling climate, terrain and vegetation properties. The advantage of WaterWorld is that it is rapid, cheap, spatially detailed, and uses sophisticated process models using the best available global datasets to assess the impacts on water-based ecosystem services of a variety of 'policy options' for land use, at the site scale, for any site globally at a 1-hectare spatial resolution. The model calculates monthly and annual hydrological water balance based on mean climatology representing the last 50 years and land cover at the year 2000. The resulting baseline distribution of water balance varies spatially with climate, landscape and vegetation cover. To assess the impacts of land use change, we applied the plausible alternative state as a land use ‘policy option’. WaterWorld then provides a series of output maps and statistics that present the differences between the altered land use and the baseline for the same region. We focused particularly on hydrological ecosystem service outputs for monthly water balance, runoff and soil erosion (as a proxy for water quality).

Cultivated goods – To estimate the average annual agricultural value per ha, we surveyed a total of 8 ha cropland across 23 households which represented 10% of the total households of Tokha and Budhanilkantha municipalities (94 in Tokha and 129 in Budhanikantha) near the park to find out the quantity and value of cultivated goods from that comparison site (for the questionnaire see Supporting Information S2). Based on variance in annual values of agricultural production reported in the first 15 interviews, we used power analysis to calculate that the minimum sample size needed to estimate annual farm output value to a precision level of 30% was 23 interviews. We also check if sample size was adequate by plotting the running means of the annual values of agricultural output per ha.

Nature-based recreation and tourism – We obtained information on the annual total number of tourists visiting the park and the entrance fees charged from the Department of National Parks and Wildlife Conservation, Nepal for the period between June 2009 and June 2010. Visitors were classified into local and international tourists. We also undertook a field survey to collect empirical data on the expenditure of visitors to the park and to determine the importance of the natural features of the park to their decision to visit. Surveys were conducted at two main entrances, initially targeting six local and six international tourists to establish the sample size required to attain a precision level of 20% for each target group – an adapted methodology from Pearson *et al*. (2005). Interviews included a mixture of fixed response and open-ended questions (see Supporting Information S3). The main objectives of the interview were to determine (1) approximate travel distance to the park; (2) cost of travel and any other costs associated with the trip; and (3) if the visitors would visit the park if 75% of the forest was converted into farmland and residential areas (the alternative state). For both visitor types, their average spends were multiplied by the annual total number of visits for that visitor category to the park to estimate their annual contributions to the nature-based recreation value of the park. The annual expenditure on visiting the park was then derived by summing the annual contributions from both national and international visitors, plus the total entrance fees collected for 2011. From this, we subtracted the value from the percentage of visitors who would still visit in the alternative state in order to estimate the net value of nature-based recreation and tourism for the park.

Conservation costs – Conservation costs were included in the calculation. The sum of conservation/management costs was taken to be the annual park management budget which includes: (1) salaries for permanent staff and army (acting as park rangers); (2) operating costs of running the reserve, e.g. equipment repairs, fuel, casual labour, staff training, reserve monitoring and protection; and (3) capital expenditure – this is the cost of purchasing equipment or facilities, e.g. investing in buildings. The conservation costs also included the budget for employing national army at the park. This data for 2011 was obtained from the park warden who was responsible for administrating the funds.

Farming costs – The assessment of the average net value per hectare took account of revenues, capital costs (e.g. transport, seeds, tools), harvesting, processing and marketing costs. We did not consider family labour as a cost item because (1) there was a constraint in the rural labour market where the unemployment rate was high; (2) members of the agrarian society–where agriculture is a primary mean of support and sustenance–were likely have a preference for "self-employment"; and (3) there were likely high commuting and accommodation costs associated with off-farm wage work. However, we considered the shadow wages for hired labour. The value per hectare was then transferred to the area of cropland in the current state (a small area linked to two settlements inside the park) and under the alternative state.

One-off windfall benefit – Economic one-off benefit of harvesting timber and fuelwood during conversion to the alternative state (i.e. no protection) was included in the assessment (Table S3). Oak and pine trees with DBH 24-36cm were included in biomass calculations as this was the main range size for harvested timber species. Area of each forest type lost is calculated based on its current proportional area of the site (of the total area of pine and oak forest, 64% is oak and

36% pine). Area of forest used for fuelwood is the total area that becomes degraded in the alternative state (for details see Table S3). Wood density conversion was taken from IPCC (2006) as the mean value for *Quercus sp*. (0.58) and *Pinus radiata* (mean 0.38). Data on price was obtained from visiting local timber yards and taking the average price for planks of each wood type.

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Supporting Information S2. Household interview questions for assessing cultivated goods, livestock and harvested wild goods.

Name/number of respondent		
Date		
Location/name of village		
Are the questions being answered per individual or household?	**Individual**	**Household**
Socio-economic information		
Through discussion with the local community a small number (4 or 5) socio-economic indicators should be identified prior to completing the questionnaires. Some suggestions are included below but these may not be relevant in the specific context of the study.		
• Are you a member of a Forest User Group?		
• What is the total area of land that you own? (ha)		
• How many rooms does your home have?		
• How many cows do you own?		
• What is the level of school education of the head of the household?		
• What is the main occupation of the major wage earner?		

Cultivated goods			
It is important here that you only focus on the main crops or products from their fields. If they have a very small patch growing something that has a low economic value then it is not worth including this			
What is your **<u>total</u>** farm size (use local units of area if appropriate):			
How many **fields** do you have?			
What are the top three most important crops that you grow?	***1.***	***2.***	***3.***
Unit ⭘			
Average price obtained per unit***** ⭘			
Percentage for own use	%	%	%
Percentage sold/ bartered	%	%	%
Daily wage rate that family members could earn doing alternative work on days spent cultivating/harvesting/processing			
Daily wage rate of hired labour			
If the crop is a perennial crop (e.g. fruit trees, vines, nut bushes, perennial herbs) ask the following:			
How much did it cost to establish the crop (e.g. plants, stakes, labour etc.)			

Complete the following, using a separate row for each field.

Notes:

- **For each crop, record the details in all columns so that these can be summed. If there are several crops grown in one field please record full details for up to a maximum of 3 per field**
- **If there is any crop residue collected for fodder, also complete the annual time taken and cost of labour for collecting this fodder**

Field number /name	**Field size**	**Main crop/crop mix or use (e.g. pasture) IN PREVIOUS YEAR** Note main crop and 2nd/3rd crops if relevant	**Total amount (**in same units as above) **of the product collected from this field in the last 12 months**	**Total amount of any crop residues collected for fodder**	**Annual time taken by respondent and family members (unpaid) to cultivate, harvest and process the product** (state units – e.g. days)	**Annual input of hired labour for cultivation, harvesting and processing** (state units, e.g. days)	**Annual cost of tools or material needed for harvesting and processing (*seeds, fertilizer, fuel, heavy machinery, land preparation, purchase, repair, maintenance*)**	**Annual transport /marketing costs**

Notes:

- If there is no livestock then just circle 'no' for this table and continue
- If they do have livestock, record details for up to a maximum of three types – based on the order of importance.
- You do not have to record three types if, for example they only have cows, just record the details for them

Livestock			
It is important to find out the value of livestock as a contribution to cultivated goods. The value of livestock is determined from the value of the fodder that is used to feed them			
Do you have any livestock on your land?	**Yes**		**No**
If yes, what?	**1.**	**2.**	**3.**
How many?			
Total area of land used for grazing *This can be calculated from the area of fields mentioned above as being 'pasture'			
Do you buy fodder or use your own land to supply it?			
Total weight/volume of fodder taken from your own land annually to feed the livestock *This can be compared to the amount declared above			
Total weight/volume of fodder purchased annually to feed the livestock			
Cost of buying fodder (per unit or to supply animals for the whole year)			
Per hectare value of cultivated feed (from total weight x price)			

Notes:

- If there is no HWG then just circle 'no' for this table and continue
- If they do harvest wild goods, record details for up to a maximum of three types – based on the order of importance.
- You do not have to record three types if, for example they only harvest one product, just record the details for that.
- If the harvest is of extremely low value or importance, please note what that product is but it is not necessary to record the value data if you consider it to be insignificant.

Harvested wild goods			
It is important to find out if any wild goods are used from the farmland. Focus on the top three most important goods.			
Do you harvest any wild goods from your farm land (including hedgerows, field trees, field borders)?			
If yes, which wild goods do you harvest from your farmland? List them in order of importance.	**1.**	**2.**	**3.**
For those products of significant value, complete the following (complete a separate form for each wild harvested product)			
Quantity and value of product			
Total quantity collected **from the site** in last 12 months ⭘			
Unit ⭘			
Percentage for own use	**%**	**%**	**%**
Percentage sold/ bartered	**%**	**%**	**%**
Average price obtained per unit***** ⭘			
Family labour			
Annual time taken by respondent and family members (unpaid) to harvest and process the product (state units – e.g. days)			
Daily wage rate that these family members could earn doing alternative work on days spent harvesting/processing			
Hired labour			
Annual input of hired labour for harvesting and processing (state units, e.g. days)			
Daily wage rate of hired labour			
Other costs			
Annual cost of tools or material needed for harvesting and processing (purchase, repair, maintenance)			
Annual transport/marketing costs			

Supporting Information S3. Interview questions for visitors at Shivapuri-Nagarjun National Park.

Site name/Location interviewed:	
Date/Time:	
Respondent number:	
1. Mode of Transport: Walk/Car/Bus/Motorcycle/Bicycle/Others(please specify)	
2. Type: National day-tripper/Domestic tourist/International tourist	
3. If applicable, how many persons in the travel group?	Number of adults Number of children (under 5)
4. Where are you from?	**For national day-trippers and domestic tourists**: Indicate which town/city: Within 10 km of this site □ Within 25 km of this site □ More than 25 km of this site □ **For international tourists**: Indicate which country:
5. Did you pay an entrance fee/permit to enter this site? (state currency)	Yes □ No □ If yes, how much _______ (indicate per person or for the whole group)
6. How much have you spent/do you expect to spend **in relation to this trip**? For each: - state currency - indicate per person or for the whole group - indicate whether the suppliers are local (< 10 km) or no-local (> 10 km). For example, a taxi/bus ride from Kathmandu is non-local, but the food/drinks bought at the stall outside the national park is local	Transport (e.g. petrol cost, bus fares etc; include return trip) ________ Food/drinks ________ Travel guides ________ Souvenirs ________ Offerings (e.g. flowers or incenses for temples/shrines) ________ Others (please specify) ________
Questions 7 – 10 for **International tourists and domestic tourists** only	
7. How many nights will you spend away from home whilst **on this whole trip**?	
8. Have you spent/do you plan to spend any nights at or near (less than 10 km) this site?	Yes □ No □ If Yes, state: (1) Number of nights at or near this site: (2) Type of accommodation: Stay with friends/Hotel/Temple/Other(please specify) (3) How much is the room rate per night:
9. In total, how much money do you expect to spend **during your whole trip** (state currency)	Estimate ________ (indicate per person or for the whole group)
10. How many days will you spend at this site **during your whole trip**?	
11. Would you come for these activities **if about 75% of the forest is converted into farmland and residential areas**? Describe the alternative state (accompany with a photograph representing this state) The farmland and residential areas near the entrance of the site can represent the alternative state. Note that the temples/shrines remain unchanged.	Yes □ No □

Table S1. Carbon prices – adjusted to 2011 – used for the sensitivity analysis of (A) carbon storage and (B) annual greenhouse gas sequestration valuation. Prices are expressed in US dollars. For the carbon stock, the difference between the current state (protection) and the most plausible alternative state (no protection) is the one-off value of the avoided carbon loss if the protected area status is removed. Carbon prices were adjusted to 2011 based on International Monetary Fund's inflation rates (http://www.imf.org/external/pubs/ft/weo/2012/01/weodata/weorept.aspx)

(A)

Source	$ Mg C (adjusted to 2011)	C storage $	
		Protection	No protection
EU Emission Trading Scheme (Point Carbon, 2012)	56.18	253,019,821	103,223,533
US Government (Greenspan Bell and Callan, 2011)	83.61	376,557,266	153,622,634
UK Govertent (Greenspan Bell and Calan, 2011)	319.33	1,438,177,632	586,727,852
Tol (2010)	118.09	531,846,042	216,975,205
Stern et al. (2006)	348.13	1,567,885,194	639,644,153
Verified Emission Reductions (Peters-Stanley et al., 2011)	22.75	102,459,967	41,800,202

(B)

Source	$ Mg $CO_{2\,eq}^{-1}$ (adjusted to 2011)	Greenhouse gases sequestration $ y^{-1}	
		Protection	No protection
EU Emission Trading Scheme (Point Carbon, 2012)	15.31	1,478,015	387,691
US Government (Greenspan Bell and Callan, 2011)	22.78	2,199,162	576,852
UK Govertent (Greenspan Bell and Calan, 2011)	87.01	8,399,873	2,203,331
Tol (2010)	32.18	3,106,630	814,886
Stern et al. (2006)	94.86	9,157,706	2,402,114
Verified Emission Reductions (Peters-Stanley et al., 2011)	6.20	598,543	157,001

Table S2. Estimated monetary one-off benefit of harvesting wood products during conversion to the alternative state (i.e. no protection).

Source of wood product (above-ground living biomass)	Biomass (Mg/ha)	Area (ha)[c]	Total biomass (Mg)	Wood Density (Mg/m^3)[d]	Biomass conversion expansion factor (BCEF)[e]	Merchantable growing stock volume (m^3)	Price (\$/m^3)[f]	Costs (\$/m^3)	Total value (\$)
Oak-dominated broadleaf forest[a]	23[b]	5,155	118,565	0.58	-	68,768	342	85	17,673,299
Pine forest (*Pinus roxburghii*)[a]	18[b]	536	9,648	0.38	-	3,666	342	85	942,224
Fuelwood removal									
Oak-dominated broadleaf forest	37	5,155	190,735	-	3.33	57,278	0.13	0	7,446
Pine forest	32	536	17,152	-	3.33	5,151	0.13	0	670
Schima-castanopsis forest	37	4,238	156,806	-	3.33	47,089	0.13	0	6,122
									18,629,761

[a] Oak and pine are used for felling according to the Nepalese tree field guide (Discovering Trees in Nepal and the Himalayas by Adrian and Jimmie Storrs published by Sahayogi Press, Kathmandu in 1984)
[b] Only trees with DBH 24-36cm were included in biomass calculations as per local timber yards reporting that this was the main range size for harvested timber species
[c] Area of each forest type lost is calculated based on its current proportional area of the site (of the total area of pine and oak forest, 64% is oak and 36% pine). Area of forest used for fuelwood is the total area that becomes degraded in the alternative state.
[d] Wood density conversion is taken from IPCC 2006 Table 4.14 as the mean value for *Quercus sp*. (0.58) and *Pinus radiata* (mean 0.38)
[e] BCEF is taken from IPCC 2006 Table 4.5 as the value for temperate hardwoods <20 m^3 growing stock level
[f] Data on price obtained from visiting local timber yards and taking the average price for planks of each wood type.

Table S3. Carbon storage in above-ground living biomass in oak-dominated forest, *Schima-Castanopsis* forest and pine forest was estimated using field surveys. The estimates of these habitats were within the estimated ranges provided by either IPCC standard table or the primary literature for similar sites. Our estimates of shrubland and grassland were derived from the IPCC standard table.

Habitat type	IPCC classification	Aboveground (C Mg/ha)	IPCC (C Mg/ha)	Literature (C Mg/ha)	References
Oak-dominated forest	Temperate broadleaf forest	284	10 - 300	179 - 297	Adhikari et al., 1995; Subedi, 2004
Schima-Castenopsis forest	Subtropical broadleaf forest	57	50 - 220	34 - 41	Baral et al., 2010; Shrestha, 2009
Pine forest	Temperate needleleaf forest	52	15 - 40	39 - 142	Baral et al., 2010; Chaturvedi and Singh, 1987
Shrubland	Temperate shrubland		24		
Grassland	Temperate grassland		1		

Table S4. Estimates of carbon stored and greenhouse gas fluxes of various habitat types in the current state (with protection) and the alternative state (no protection) of the Shivapuri-Nagarjun National Park. AGB, BGB, dead, CO_2, CH_4 and NH_4 denote above-ground biomass, below-ground biomass, dead wood, carbon dioxide, methane and nitrous oxide, respectively. Negative values indicate greenhouse gas emission by the habitats. For soil, the IPCC guidelines suggest a nominal error of ±90%. Above-ground carbon is calculated to a precision of 20%. The maximum and minimum litter and deadwood carbon stocks in forests and shrubland were estimated by multiplying those of AGB with conversion factors derived from Brown (1997), IPCC (2006) and Marklund and Schoene (2006). Potential range is the maximum and minimum estimates, summed across the five carbon pools.

State	Habitat type	Habitat coverage	Carbon storage (Mg)							Greenhouse gas sequestration (Mg CO_2 eq y^{-1})			
		(%)	AGB	BGB	Litter	Dead	SOM	Total	Potential range	CO_2	CH_4	N_2O	Total
Protection	Oak-dominated broadleaf fore	45	2016914	605074	100846	806766	241785	3771384		48499	602	-2408	46693
	Schima-castanopsis forest	33	300153	90046	15008	120061	178444	703712		35794	444	-1777	34461
	Pine forest	5	39105	11340	1955	15642	25643	93686		5144	64	-255	4952
	Shrubland	12	46410	129949	2321	18564	65748	262991		11997	135	-327	11805
	Cropland	5	886	2482	0	0	26207	29575		0	37	-1516	-1479
	Grassland	0	0	0	0	0	2643	2643		116	4	-13	107
	Bareground	0	0	0	0	0	131	131		0	0	0	0
	Built up	0	0	0	0	0	0	0		0	0	0	0
	Total		2403469	838891	120129	961033	540600	4864122	3512878 - 6215367	101550	1286	-6297	96539
No protection	Oak-dominated broadleaf fore	12	554855	166457	27743	221942	66515	1037512		13342	166	-662	12845
	Schima-castanopsis forest	6	57807	17342	2890	23123	34367	135530		6894	86	-342	6637
	Pine forest	1	11326	3285	566	4530	7427	27134		1490	18	-74	1434
	Shrubland	17	65885	184477	3294	26354	93336	373346		17031	192	-465	16758
	Cropland	41	7467	20909	0	0	220776	249152		0	311	-12770	-12459
	Grassland	0	0	0	0	0	2643	2643		116	4	-13	107
	Bareground	0	0	0	0	0	131	131		0	0	0	0
	Built up	21	0	0	0	0	115405	115405		0	0	0	0
	Total		697341	392469	34494	275949	540600	1940853	1174262 - 2707443	38873	777	-14327	25323